Autumn 2010

NOAA's Northeast River Forecast Center

Various NWS March Flood Photos (courtesy Nicole Belk, Taunton WFO)

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NOAA's Northeast River Forecast Center

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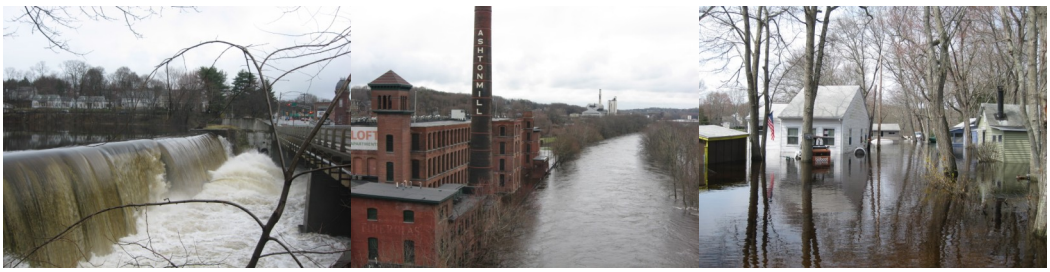
From the Desk of the HIC

David Vallee
Hydrologist-in-Charge

Much of eastern New York and central and southern New England experienced multiple moderate to major floods during the late winter and early spring of 2010. Flooding across parts of Rhode Island, southeast Connecticut and eastern Massachusetts were historic, with several locations subjected to not one but two record floods within a two week period. The driving force behind this dramatic and devastating 5 week period was a series of four major rain-producing nor'easters. Each system was enhanced by the tremendously active southern jet stream and plumes of deep tropical moisture originating from the moderate El Nino event in the tropical Pacific. The systems also spent multiple days raining over the region, blocked in their forward progress by a persistent ridge of high pressure over Greenland.

The combined effects of power-house, moisture laden, slow moving nor'easters would play out across the region in the form of heavy rains and record breaking flooding. By the time the rains had ended and flood waters had subsided, damages in the hardest hits states of Rhode Island and Massachusetts were in the millions of dollars. Hundreds of roads and bridges were damaged or destroyed. Dozens of dams were pushed to the brink, with several failing under the strain of 10 to 20 inches of rainfall in a 5 week period. Lastly, thousands of residents in the region were forced to leave their homes and businesses, with some still unable to return or rebuild as I write this today.

This newsletter focuses on the hydrometeorological conditions which ever so steadily brought the region to such a historic point in its flood history. The staff at the Northeast River Forecast Center performed exceptionally well, with remarkable lead times for major and record breaking flooding. While we have had several significant flood events since I became Hydrologist-in-Charge in 2007, the sequence of events from late February through the end of March was one of the most intense and challenging episodes in my tenure.



Retirement of the Hartford API Model

Robert Shedd, Development and Operations Hydrologist

The Northeast River Forecast Center (NERFC) was established in August 1955 and was initially located in Hartford, Connecticut. One month later, Hurricanes Connie and Diane devastated New England with some of the worst flooding that had been recorded in the region. While information is unavailable regarding what support and forecast procedures the NERFC may have utilized in 1955, the lessons learned and data collected during September 1955 certainly had an important influence on the development of forecast procedures that would subsequently be used at the office. In 1960 and 1961, Charles Hopkins, the NERFC Hydrologist-in-Charge, published papers describing what we refer to today as the Hartford Antecedent Precipitation Index (API) model.

Over the years, many versions of API models have been utilized. They rely on defining soil moisture as a function of rainfall over the past few weeks with increasing weight given to rainfall in the more recent past. Given their ability to represent rainfall runoff processes within a 3 or 4 quadrant chart, API models were widely used during the early years at many River Forecast Centers. One characteristic that made the Hartford API model somewhat unique was the manner in which the model incorporated temperature and season of the year within an antecedent temperature component. Inclusion of the Antecedent Temperature Index was shown to significantly improve the rainfall – runoff relationship for the river forecast procedures.

Use of the Hartford API model continued at the NERFC from the early 1960's. Although its form changed from the early paper charts, the basic model persevered and was coded for use on a variety of computer systems over the years. The most recent implementation was in 1994 when the API model was converted for use in the National Weather Service River Forecast System (NWSRFS).

However, the final NERFC run of the API model was made in September 2010. Over the past 10 years, work has been in progress to transition to the

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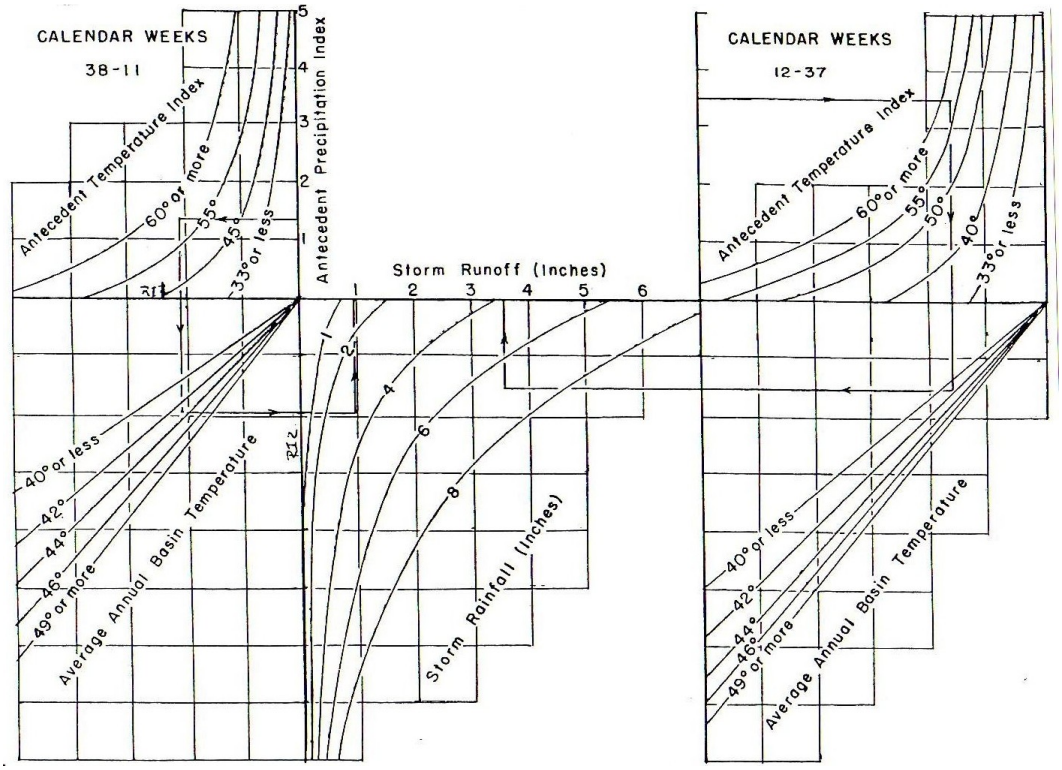

Figure 1. Hartford API Rainfall-Runoff Relationship for New England and eastern New York based upon Average Basin Temperatures (Hopkins and Hackett, 1961)

The Storms and Floods of March 2010

Steven Nogueira, HAS Forecaster, and
David Vallee, Hydrologist-In-Charge

The following article provides a hydrometeorological review of the dramatic evolution of storms which ever so steadily brought the region a series of historic flood events commencing in late February and reaching its climax at the end of March. Each of these storms had a very common theme: each was energized from the El Nino enhanced southern stream jet, each was able to tap a deep and persistent plume of tropical moisture, and each was forced to move slowly, impeded by high pressure in the mid and upper atmosphere located in position over Greenland – a classic negative phase of the North Atlantic Oscillation (NAO). Working in concert, these ingredients would produce four major precipitation events, resulting in record breaking monthly rainfall and historical river and stream flooding across much of southern and eastern New England.

Event #1: February 24-26, 2010 – minor to moderate flooding

The first event occurred during the last week of February. Low pressure developed off the mid Atlantic States and intensified explosively as it moved toward Cape Cod. Very heavy rain fell due to cyclogenesis and a long duration of easterly upslope flow and orographic enhancement. A complicating factor for this particular event was determining whether mountain areas would receive rain or snow.

Initially, heavy rain worked northward into southernmost New England and into the lower Hudson River valley. As the system intensified, most of the heaviest rain fell across southern and eastern New England, where 3 to 7 inches of rain was noted over the 3 day period from February 24 through 26. The highest rainfall totals were in southwestern Maine. Heavy precipitation also fell from the Adirondacks southward through the Catskills and lower Hudson River Valley.

Due to the cut-off nature of the upper level system a very unusual temperature regime became established by strong easterly on-shore flow and a very cold pool of air over southern New York. As the low pressure system developed, cold air was drawn in on the western side of the storm system, changing rain to heavy wet snow across the higher terrain. Some locations received a foot of snow after receiving heavy rain. As the storm moved away these locations then saw a change to light rain again.

It had been nearly a month since the last significant precipitation event in late January. Rivers and streams had returned to normal base flow conditions by the time this system approached the region. As a result of the heavy rains and snow, minor river flooding occurred at thirteen river forecast locations stretching from the Housatonic basin in western Connecticut northeastward to the mid Merrimack River basin in New Hampshire. Three locations reached or exceeded moderate flood stage, as provided in table 1 below. The NERFC forecast lead time for those locations reaching flood stage averaged approximately 14 hours for this event.

(continued)

Station	FS	Mod	Maj	Crest	Crest UTC mm-dd hh:mm	Flood UTC mm-dd hh:mm
Pawtuxet River Cranston, RI	9	11	13	11.37	02-26 21:15	2/24/2010 23:15
Assabet River Maynard, MA	5	6	7	6.39	02-26 23:00	2/26/2010 3:00
Shawsheen River, Wilimngton, MA	7	8	10	8.15	02-26 16:30	2/26/2010 2:15

Table 1. Summary of moderate flooding for the February 24-26 event.

March 2010 Storms…
(continued from previous page)

Event #2: March 13-15, 2010 – record flooding

The second significant rain event occurred during March 13th through the 15th. An anomalous low pressure system moved from the central Plain States to the mid Atlantic coast, then rapidly intensified while moving slowly south of New England. Coincident with this pattern was a strong high pressure system over the Canadian Maritimes. This set the stage for unusually strong winds in the lower and mid atmosphere, which helped to transport deep moisture into southern New England.

As the low pressure system approached the coast, winds just a few thousand feet off of the surface increased to 60 knots. These winds nearly perpendicular to the orography resulted in unusually distinct patterns of upslope enhanced rainfall and downslope decreased rainfall. The duration of the event and abundant moisture resulted in heavy rainfall where upslope was enhanced by the strong winds. In addition, another precipitation maxima was observed just inland, where strong low level convergence occurred as winds blew onshore. Total rainfall across southern New England ranged from 3 to 5 inches, with the heaviest amounts occurring across parts of Connecticut, Rhode Island, and southeastern Massachusetts.

Only two weeks had passed since the late February floods and most rivers and streams had not completely receded since the earlier flooding. In addition, typical Spring vegetation growth was delayed, which led to enhancement of the runoff generated by this system. With little transpiration occurring, soil moisture was quite high, which set the stage for dramatic rises and record flooding on some rivers in the region.

By the time this event was over, a total of twenty-seven river forecast locations from western New York to northern New Hampshire had exceeded flood stage. Twelve locations exceeded moderate flood stage, with five of them exceeding major flood elevations. Of the five major flood locations, two established new record flood stages. The hardest hit basins included the Pawtuxet River at Cranston, RI, which crested at 14.98 feet (surpassing the previous crest of 14.50 feet set in June, 1982), and the Shawsheen River at Wilmington, MA, which crested at 10.59 feet (surpassing its record of 10.49 feet set in October 1996). On average, NERFC forecasts provided at least 26 hours of lead time to flood, with several locations having more than 36 hours lead time. The average lead time for moderate and major flooding locations was 10 hours. Table 2 shows a summary of all forecast locations which exceeded moderate flood elevations for this event.

Event #3: March 22 - 24, 2010 – renewed moderate flooding

The third event in this devastating sequence of heavy rainstorms struck the region on March 22-24. A classic wintertime redeveloping nor'easter moved up from the Mid-Atlantic coast, producing another round of significant rains less than a week after the major-to-record floods. The primary low pressure system tracked northeastward into the Ohio Valley, then redeveloped south of New England. The new low pressure system then tracked across eastern New England and into Maine.

Initially, this system fed on abundant moisture drawn northward on southerly winds in the mid and upper atmosphere. This brought heavy rain to eastern New York and southern New England, with some upslope enhancement noted. As the storm redeveloped and moved northeast, the mid-level winds turned easterly into the White Mountains. Upslope enhancement became dramatic once again along the White Mountains and eastward into Maine. With this system, 2 to 4 inches of rain fell in the southeast facing Catskills, the Adirondacks, and across southern New England. Much more widespread amounts of 2 to 4 inches were also noted from the coast of Maine northward through the White Mountains and eastward into the Longfellow Mountains.

(continued)

Station	FS	Mod	Maj	Crest	Crest UTC mm-dd hh:mm	Flood UTC mm-dd hh:mm
Pawtuxet River Cranston, RI	9	11	13	14.98	03-15 19:45	3/14/2010 8:45
Nashua River East Pepperell, MA	8	12	15	e16.00	03-16 23:00	3/15/2010 4:30
Charles River Dover, MA	5	7	8	7.38	03-17 00:00	3/14/2010 20:30
Piscataquog River Goffstown, NH	9	10	12	10.1	03-15 13:30	3/15/2010 1:30
Assabet River Maynard, MA	5	6	7	7.14	03-16 03:00	3/14/2010 17:30
Spicket River Methuan, MA	8	9	12	9.86	03-16 20:30	3/15/2010 5:00
Neponset River Norwood, MA	9	10	11	11.07	03-15 18:15	3/14/2010 16:30
Sudbury River Saxonville, MA	10	12	13	12.92	03-16 04:15	3/14/2010 10:45
Shawsheen River Wilmington, MA	7	8	10	10.59	03-16 01:30	3/14/2010 18:00
Lamprey River Newmarket, NH	8	14	17	14.81	03-16 18:45	3/14/2010 22:00
Suncook River North Chichester, NH	7	12	16	12.45	03-15 20:00	3/14/2010 18:15
Yantic River Yantic, CT	9	9.5	11	10.63	03-14 14:45	3/14/2010 10:15

Table 2. Summary of forecast moderate or greater flooding for the March 13-15 event. Red background indicates moderate flooding, purple is major flooding, and light blue is record flooding.

This storm struck just a few days after the previous major-to-record flood crests were observed. While this was the smallest rainfall producer of the four storms, it proved to be one of the most important events for southeast New England. Rivers and streams had little opportunity to evacuate the rains of the previous week, and this 2-to-4 inch event brought soil moisture and ground water tables to the breaking point. Runoff from this event produced renewed minor to moderate flooding at twenty-eight locations from eastern New York to Maine, with three locations experiencing moderate floods, as noted in table 3 below. NERFC forecasts provided an average of 24 hours lead time for all locations exceeding flood elevations and 5 hours for those exceeding moderate floods.

(continued)

Station	FS	Mod	Maj	Crest	Crest UTC mm-dd hh:mm	Flood UTC mm-dd hh:mm
Schoharie Creek Breakabeen, NY	6	8	10	8.48	03-24 00:00	03-21 15:04
Schoharie Creek Prattsville, NY	12	14	16	14.01	03-23 09:45	03-21 15:04
Pawtuxet River Cranston, RI	9	11	13	11.88	03-25 00:45	03-23 17:00

Table 3. Summary of moderate flooding for the March 22-24 event.

March 2010 Storms…
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Event #4: March 29-31, 2010 – catastrophic 500-year (0.2% recurrence interval) flooding

The final rainfall event of this remarkable 5 week period occurred from the 29th through the 31st. By the time this event approached the region, portions of southeastern Connecticut, Rhode Island, and eastern Massachusetts had already received 2 to 3 times the normal rainfall for the month. River flows were uncharacteristically high and soil moisture and ground water was exceedingly wet.

Initially, a deep fetch of southerly winds from the Gulf of Mexico were noted ahead of a cold front that extended through eastern New York and southern New England. An atypical "upslope-downslope" pattern was observed over the Catskill and Adirondack mountains, with distinct rainfall maxima over the southern slopes and distinct rainfall minima over the northern sides. As the front continued eastward, low pressure rapidly developed off the mid Atlantic States and moved slowly north, once again blocked by a large high pressure center in the Canadian Maritimes and fed by an energized sub -tropical jet stream and a deep tropical moisture plume.

The slow movement of the storm and tropical moisture source resulted in extreme rainfall totals in southern and eastern New England. Widespread 5-to-7 inch amounts were noted across eastern Connecticut, Rhode Island, and eastern Massachusetts, with over 9 inches in portions of southern and western Rhode Island, as intense convection tracked over the region. In addition, onshore flow produced significant upslope enhancement across southern New England, southern Vermont, New Hampshire, and Maine. Widespread 3-to-5 inch amounts were also observed along the east side of the mountains and higher terrain, with as little as a quarter of an inch in the Connecticut River Valley of northern New England.

Hydrologically speaking, the region was already saturated prior to the start of this event. Ponds, lakes, and reservoirs were either full or already spilling considerable amounts of water through their spillways and into their downstream channels. This was especially true for the Scituate Reservoir in Rhode Island, which feeds the north branch of the Pawtuxet River. New records for spillway elevation and flow had been observed during the week of March 15th, only to be broken by a remarkable three feet in elevation at the height of this event. At its peak, the water level coming over the Scituate Reservoir spillway was 3.5 feet over the flashboard.

At the height of this event, 43 forecast points went into flood stage, with 12 of them exceeding moderate flood stage elevations. Seven of the locations made it to major flood stage and three points established new record flood elevations, some of which were subsequently determined to match or exceed the 0.2% recurrence interval flood.

The Taunton River at Bridgewater, MA and the Sudbury River at Saxonville, MA were two very hard hit forecast points, both of which recorded new record flood elevations. Flooding impacted residential and business areas and shut down major roadways in the communities for days. As dramatic as these responses were, clearly more devastating flooding struck the lower Pawtuxet River basin. Just two weeks prior, the Pawtuxet River at Cranston, RI had established a new record flood elevation. By the morning of March 31, that record was obliterated by an unthinkable crest almost 6 feet higher at 20.79 feet. This flood was later classified by the USGS as a < 0.2% recurrence interval event.

Business and residential neighborhoods in the lower Pawtuxet basin were flooded to the rooftops and thousands of people were forced from their homes. Neighborhoods along the river, some of which had never experienced flooding, were under 2 to 4 feet of water. At the height of the flooding, the popular Warwick Shopping Mall, containing over 80 businesses, was also nearly 2 feet under water. By the evening of March 30th, Interstate 95 was closed, as it became submerged beneath 2 - 3 feet of water from

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March 2010 Storms…
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the Pawtuxet River. Three waste water treatment facilities were inundated, with the Warwick and West Warwick facilities hardest hit. At the West Warwick facility alone, it was estimated that nearly 25 million gallons of untreated sewage was passing the plant and flowing into the floodplain.

While the urban impacts along the Pawtuxet represented millions of dollars worth of damage, flooding conditions were just as severe in southeastern Connecticut and southwestern Rhode Island, particularly in the Yantic and Pawcatuck watersheds. Flooding along the Pawcatuck River and its major tributary, Wood River, was compounded by at least one dam failure during the event.

NERFC began producing contingency forecasts and assisting with state and federal coordination for this event on Thursday, March 25th. The first flood outlook for likely significant flooding was issued on Saturday, March 27th, five days in advance of the record flooding. Based on forecast guidance, the average lead time to flood for those locations that exceeded flood elevation was a remarkable 43 hours. The average lead time to flood for those locations experiencing moderate and major flooding was 33 hours. Table 4 below summarizes the flooding for this historical flood event.

(continued)

Station	FS	Mod	Maj	Crest	Crest UTC mm-dd hh:mm	Flood UTC mm-dd hh:mm
Taunton River Bridgewater, MA	11	12	14	14.97	04-01 10:00	3/30/2010 14:15
Pawtuxet River Cranston, RI	9	11	13	20.79	03-31 13:15	3/29/2010 20:30
Nashua River East Pepperell, MA	8	12	15	13.78	04-01 19:00	3/31/2010 1:45
Charles River Dover, MA	5	7	8	8.05	04-03 00:15	3/28/2010 0:00
Merrimack River Lowell, MA	52	54	58	54.64	04-01 13:45	3/31/2010 9:30
Assabet River Maynard, MA	5	6	7	7.08	03-31 15:00	3/30/2010 12:15
Connecticut River Middletown, CT	8	12	15	12.96	04-02 07:45	3/28/2010 0:00
Neponset River Norwood, MA	9	10	11	11.16	03-30 21:15	3/30/2010 6:00
Sudbury River Saxonville, MA	**10**	**12**	**13**	**13.99**	**03-31 22:00**	**3/29/2010 23:15**
Shawsheen River Wilmington, MA	7	8	10	9.42	03-31 16:15	3/30/2010 20:15
Blackstone River Woonsocket, RI	9	12	16	14.5	03-31 09:30	3/30/2010 7:00
Yantic River Yantic, CT	9	9.5	11	13.23	03-30 21:30	3/29/2010 23:45

Table 4. Summary of forecast moderate or greater flooding for the March 29-31 event. Red background indicates moderate flooding, purple is major flooding, and light blue is record flooding.

March 2010 Storms…
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Epilogue

People who live through a flooding episode will often try to equate the flooding to a single rain event exceeding some standard threshold, such as a 50-year or 100-year event. It is important to note that, in this sequence of events, no one single storm reached the established one or two day rainfall for a 100-year return period event. Rather, the trigger for the record flooding was the remarkable accumulation of events that occurred over the span of approximately 5 weeks, all before vegetation had bloomed and close enough in succession that ground water, soil moisture, rivers, and streams never had an adequate recovery period.

In looking back at this historical sequence of events, it clearly deserves its place amongst the most significant floods in the region, such as the November 1927 floods, the March Snowmelt Floods of 1936, The Hurricane of 1938, Connie & Diane in 1955, the October Floods of 1996, the October Floods of 2005, the Spring Floods of 2006 and 2007, and, most recently, the devastating Saint John River Flood of April 2008. Remarkably, and thankfully, no deaths have been directly attributed to the record flooding of 2010.

Height of Pawtuxet River Record Flooding, March 31, 2010. Intersection of Providence and Wakefield Streets, West Warwick, Rhode Island

Hartford API Model…
(continued from page 2)

Sacramento model as the basis of our forecast operations. Two primary changes led to this conversion: The first was a need to provide improved water resources and reservoir management information over a wide range of flows. The API model was developed and calibrated primarily as a flood forecast model and focused on heavy precipitation events. It performed this function very well for many years, but it was limited when tasked with providing low and moderate flow information. The second, and more critical, change has been a move towards longer term and probabilistic forecast information from the NWS. As an event based model, the API model was unsuited for this task. Based on this realization, a decision was made to move away from the API model, and when planning for introduction of the Community Hydrologic Prediction System (CHPS) into NWS operations was undertaken, it was decided not to convert the API model for use in the CHPS environment. Now, the last remaining API forecast locations have been converted for the Sacramento model and the API model has been retired.

It is a testament to Charles Hopkins and the other developers of the Hartford API model that the work they developed over 50 years ago stood the test of time and was able to be successfully migrated into the digital age to serve as the basis of river forecasting in the northeast for many years.

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The NERFC Nor'easter is a semi-annual publication of the Northeast River Forecast Center which is part of NOAA's National Weather Service. Your comments are welcome.